

The FFAG is a Challenge

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Studies

- MURA studies 50 MeV e-model
- CERN ~ 1956 10-40 GeV 40 000t magnets
- GSI Study early 70's
- ANL study on contract for Jülich 1981-84
Option for the german spallation neutron source SNQ
200(400)-1100 MeV
- ASPUN proposal Argonne 1985
- System studies for the European Spallation Source ESS
1992-1995
- KEK PoP 2000 & 150 MeV Model

FFAG topics

- FFAG principle is developed by the MURA group in the 50's
- Engineering of very large complicated magnets
- Nowadays superconducting magnets
- New material for RF systems
- very large acceptance

FFAG topics 2

- Charge exchange injection at relatively low energies Engineering of very large complicated magnets
- Low losses during acceleration
- State of the art kicker extraction

FFAG basic design tools for the radial type FFAG

- The radial type FFAG consists of pure radial sector type bending magnets without spiral angles. The magnets have an alternating bending direction. The most simple structure is a lattice called
$$\mathbf{N}^*(\mathbf{P}-\mathbf{M})$$
- P positive or inward bending dipoles,
- M minus or outward bending;
- N Number of sectors.
- Other combinations like $\mathbf{N}^*(\mathbf{M}-\mathbf{P}-\mathbf{M})$ are possible

FFAG basic design tools 2

- **field gradient**

$$\frac{B(r)}{B(r_0)} = \left(\frac{r}{r_0} \right)^k$$

- **Curvature radius ρ , system radius r**

$$\frac{d \rho}{\rho} = - \frac{d B}{B} = - k \cdot \frac{d r}{r}$$

FFAG basic design tools 3

- In the smooth approximation the tunes are given as

$$Q_x^2 = k + 1 + k^2 \cdot G^2$$

$$Q_y^2 = -k + k^2 \cdot G^2 + \frac{F^2}{2}$$

$$\frac{B(r, \theta)}{B_0} = \left(\frac{r}{r_0}\right)^k \sum_{n=0}^{\infty} \{g_n \cdot \cos(n \cdot N \cdot \theta) + f_n \cdot \sin(n \cdot N \cdot \theta)\}$$

g_n, f_n Fourierharmonics of the field

FFAG basic design tools 4

Fraction of ring covered by magnets

$$\frac{P + m^2 M}{2\pi R} = \left[\frac{B\rho}{B_0 R} \right]^2 \left[\frac{F^2}{2} + 1 \right] = \left[\frac{B\rho}{B_0 R} \right]^2 \frac{\langle B^2 \rangle}{\langle B \rangle^2}$$

$$\frac{P + m^2 M}{2\pi R} = \left[\frac{B\rho}{B_0 R} \right]^2 \left[\frac{Q_x^2 + Q_y^2 - 2k^2 G^2 - 1}{1 + 2\tan^2 \varsigma} + 1 \right]$$

$$\gamma_{tr} = \sqrt{k + 1} \quad \frac{B}{B_0} = \left(\frac{r}{r_0} \right)^k$$

Scaling laws

- $R=\text{const.}$, $Q_{x,y}=\text{const.}$, $B_r=\text{const.}$:
- Doubling $B_0 \rightarrow$ length goes down to 25% !!
-> **superconducting magnets**
- Increasing Flutter increase Q_x
increases magnet length
- Increase field **reduce flutter**
- **Reducing radius by f.of 2
doubles magnet length
quadruples r. cov. By magnets**

Data of an 800 to 2500 MeV FFAG

beam parameters	beam power	5	MVA
	Energy extr.	2500	MeV
	rep. rate	50	Hz
magnet parameters	Radius extr.	38	m
	Field extr.	5	T
Circumference		239	m

Data of an 800 to 2500 MeV FFAG 2

Beam Power	5	MW
average beam current	2	mA
Energy inj.	800	MeV
Energy extr.	2500	MeV
Radius inj.	36.31	m
Radius extr.	38	m
k_value	16.90	
Lattice		
Phase adv. cell x	71.7	degree
Qx	4.78	
beta(xmax)/R	0.962	
beta(xmax)	36.6	m
beta(ymax)/R	0.95	
beta(ymax)	36.1	m
DQ Las lett	0.5	
No of part	2.50E+14	
Cell Length	11.938	m
emittance norm	122	mm mrad

Magnets :		
Number of Magnets	20	
positive bend	32.8	deg
Vacuum Chamber clea	286	mm
Field extr.	3.43	T
Max. Ampere Turns	2.106	MA
Iron Weight	243	t / Magnet

bend_angle	18	degree
neg. bend half	14.8	deg
Magnet Gap max.	306	mm
Field inj.	1.21	T
Supercond. Coils	2	per Cell
Max. Thermal Loss	20	W / Magnet

Data of an 800 to 2500 MeV FFAG 3

RF		
Number of Cavities	6	
Physical Length	1.25	m
Volume of Ferrite	0.8	m^3
Maximum RF Voltage	93	keV / Turn
Average RF Power	7.5	MW
Frequency at Injection	1.106	MHz

Cavity Type	Single ended, Ferrite Loaded
Active Ferrite Length	0.8 m
Ferrite Type	Philips 8C12
Peak Voltage	20 kV / Cavity
Frequency at Extraction	1.208 MHz

Extraction					
Beam Disp. at Septum	214	mm			
beta Kicker	32.00	m	beta septum	32	m
Kick Angle	7.05	mrad	B*L	0.07773787	Tm
Kicker Length	1.55	m	Kicker field	0.05	T

Data of an 800 to 2500 MeV FFAG 4

